RESEARCH HIGHLIGHTS

Technical Series 00-138

PERFORMANCE OF A BRICK VENEER/STEEL STUD WALL SYSTEM

Introduction

Steel stud framing is an inexpensive, space-saving system for support of lateral loads on brick veneer exterior walls, used extensively over the last 20 years on high-rise residential buildings. Performance, particularly in management of moisture, and consequent durability, has not always been satisfactory. Is this because of negligent design and construction, or is the system inherently vulnerable?

When this study was initiated, CHMC had previously funded extensive laboratory and field research, and was preparing a *Best Practice Guide* that recommended improvements over prevalent practice, based on the research findings. There was (and is) controversy, however, about the recommended practices. What improvements, if any, are really necessary? Can satisfactory performance be attained by careful execution of a typical design?

Research program

The subject of the research summarized here is an exterior wall section on the top floor of a seven-storey residential building in Ottawa. It was built in 1990. Instrumentation was incorporated in the wall to allow temperatures, air pressures, and moisture in key locations inside and outside the wall to be monitored and recorded. Moisture was sensed as humidity in air, as water on surfaces and as water absorbed in materials. The sample wall was on the lee side of the building with respect to prevailing winter winds. Thus, combined stack, wind, and fan pressures would maximize air leakage in cold weather. This orientation placed the wall on the windward side during prevailing rains, maximizing exposure to moisture from rain as well as from winter air leakage and resulting condensation. The project was selected because the designers, contractors and owner were all willing to participate.

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Prior to construction, possible shortcomings of the proposed design in relation to best practice were discussed. The only modification introduced as a result was to have an engineer design the framing and prepare shop drawings. The wall consisted of:

- 90 mm brick masonry veneer
- 25 mm air space
- building paper
- gypsum sheathing
- 150 mm steel studs
- batt insulation in the stud space
- polyethylene vapour barrier
- interior gypsum board

The cavity was flashed and drained, but not compartmented. Slab edges were insulated within the cavity, reducing cavity depth at those locations.

The steel stud framing included the following:

- Studs: 150 x 38 mm 1.53 mm @ 600 o.c., Z275 zinc coated.
- Ties: 2 part, with slotted C-plates attached to stud webs @ 400 o.c., with 4.5 mm diameter hot-dip galvanized wire extending from sheathing face to veneer.

The researchers observed the wall during construction and found that it generally conformed to the design. The workmanship was of above-average quality. Thermocouples, relative humidity sensors, moisture sensors and pressure taps, along with a computer system to collect and record data, were installed. **Photograph 3** shows the wall during construction, with studs, insulation and vapour barrier in place.

The installation was monitored, with data read minute-by-minute and recorded as hourly averages, minima, and maxima, over several two-week periods, spread through all seasons of the year, starting in the winter of 1991 and extending to summer of 1997. For analysis, weather records from the local airport were also used.

At the beginning of Phase 4 (October 1996—July 1997) vent openings were added by removing the mortar in every second head joint in the top course of brick.

Findings and analysis

Thermal bridging

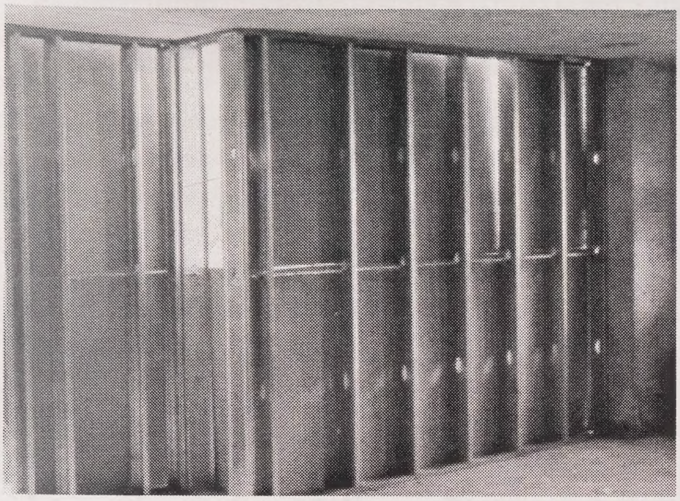
Thermocouples on stud flanges recorded different temperatures than those located on the corresponding gypsum board surfaces midway between studs. **Figure 1** shows the thermal profile through the wall at a stud, while **Figure 2** shows the profile midway between studs, for the same time period.

The temperature drop across the stud space is larger midway between studs than at a stud. At the stud, the stud space contributes about half of the total temperature difference, while midway between studs it contributes between two thirds and three quarters of the total. Since the thermal resistances of all the other components (air films, drywall, brick, and cavity) are the same in both cases, this is an indication of the extent of thermal bridging.

In -20° C weather the interior surface was as much as 3.5° C colder at the stud locations than midway between studs. Severe dust patterns indicating stud locations (and even drywall screws) were observed after the first year, as can be seen in **Photograph 5**.

Pressure differences

Pressure taps were located at the exterior, in the cavity, in the stud space, and on the interior. **Figure 3**, typical for winter conditions, shows that the pressure on the interior was usually higher than on the exterior. The pressure difference driving air outward was reduced, but not reversed, by wind toward the wall, and wind away from the wall increased it. The graph also shows that the cavity behind the brick is pressure-moderated, not pressure-equalized. In fact, at least in winter, the cavity at this location was usually at a higher hourly average pressure than if it had been compartmented and pressure-equalized to the exterior. Two significant pressure drops occur, the first from the interior to the stud space, the second across the brick veneer. The relative magnitude varies, but at times the pressure difference across the brick is larger than that across the rest of the wall. Dust left in the insulation, shown in **Photograph 4**, is a further indication of air leakage.



Photograph 1: Framing and Exterior Sheathing
The sheathing is not fastened against the framing yet, but when it is, gaps will remain at the joints that make the sheathing the least air-tight layer in the wall.

Photograph 3: Insulation and Vapour Barrier
The polyethylene vapour barrier is sealed at laps and to adjoining concrete. Electrical outlets have polyethylene back pans, and other penetrations are sealed. For a wall that depends on the vapour barrier to be an air barrier as well, it is reasonably tight.

Photograph 2: Sheathing Paper and Masonry Ties
The sheathing paper is lapped to drain, but will not be a barrier to exfiltration. The corner column is insulated on the exterior with rigid extruded polystyrene insulation. At the bottom of the cavity, rigid insulation on the slab edge (covered with paper in this view) extends outward from the plane of the wall, narrowing the cavity at the bottom.

Figure 1: Temperature profile at stud

Trace 1: (top) interior drywall surface
Trace 2: exterior flange of steel stud
Trace 3: exterior sheathing surface
Trace 4: (bottom) exterior air

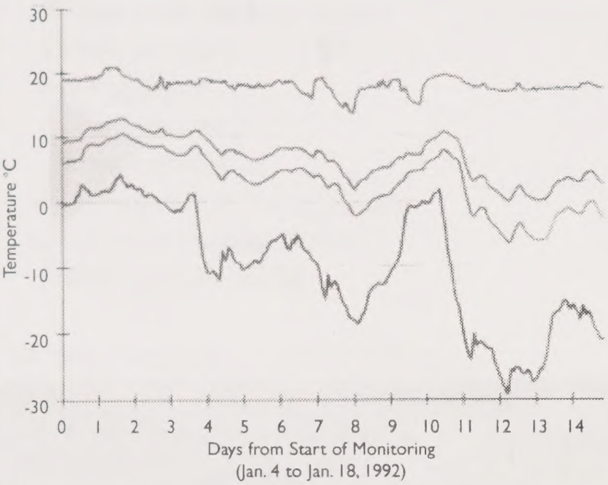


Figure 2: Temperature profile at insulation

Trace 1: (top) interior drywall surface
Trace 2: sheathing surface next to insulation
Trace 3: exterior sheathing surface
Trace 4: (bottom) outside air

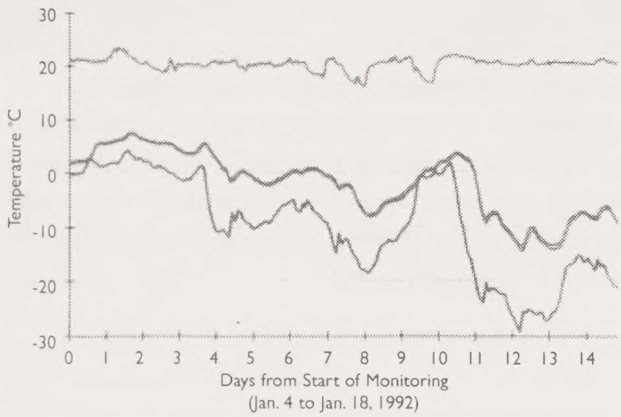


Figure 3: Hourly average pressure differences (before modification of venting)

Trace 1: (top) inside air- to-stud space
Trace 2: inside air-to-cavity
Trace 3: (bottom) inside air-to-exterior

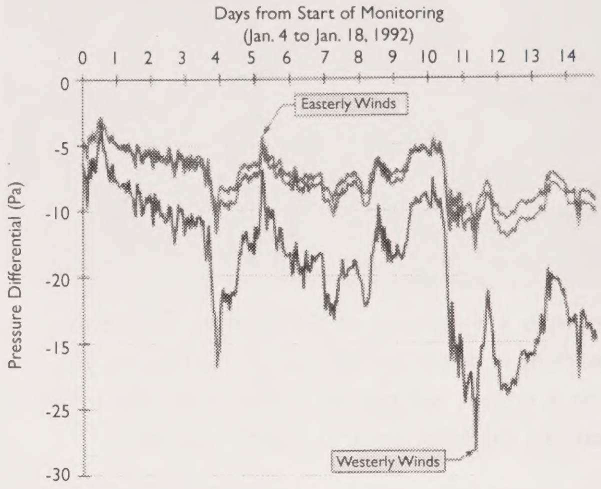


Figure 4: Hourly average pressure differences (after adding cavity vents)

Trace 1: (top) inside air-to-stud space
Trace 2: inside air-to-cavity
Trace 3: (bottom) inside air-to-exterior

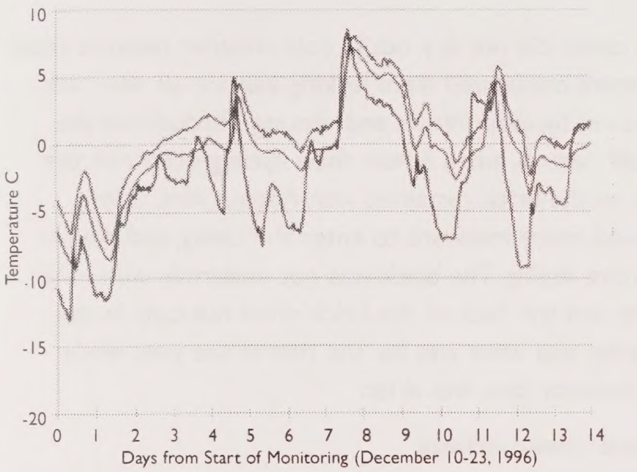
Figure 4 shows that the resistance of the brick veneer remained significant after the addition of vents. The contribution to air flow resistance of the brick was reduced from about a half of the total pressure drop to about a third, while the pressure across the air barrier increased to about two thirds. (Note that 0 Pa is not at the top of the graph, as it is in Figure 3). Because flow increases exponentially with pressure difference, with the same equivalent leakage area of the interior air barrier, adding the vents presumably caused an increase in air leakage.

Condensation

As a result of air leakage primarily, condensation occurred on the inner surface of the brick veneer almost all of the time during late fall and winter. **Figure 5** shows the surface temperature at the back of the veneer, in relation to the dewpoint temperature of the air in the cavity and the exterior air temperature. During the period shown, the brick surface temperature was constantly below the dewpoint temperature, indicating that condensation was occurring. Even when exterior air temperature rose above the cavity dewpoint (when a period of drying might be expected), although the cavity dewpoint temperature rose, the brick remained colder.

Figure 5: Temperatures of interior brick face, cavity dewpoint, and exterior air

Trace 1: (top on day 0, and most of the time): cavity dewpoint temperature
Trace 2: temperature at back of brickwork
Trace 3: (bottom on day 0, and most of the time, with three spikes extending above the other two traces): exterior air temperature



The corresponding situation was similar for the back of the sheathing and the dewpoint temperature of the air in the stud space. While the coldest part of the stud, the exterior flange, was always warmer than the dewpoint temperature of the air in the stud space, the inside face of the sheathing midway between studs was consistently below dewpoint temperature. The mold seen on the back of the sheathing after a year, shown in **Photograph 6**, is further evidence.

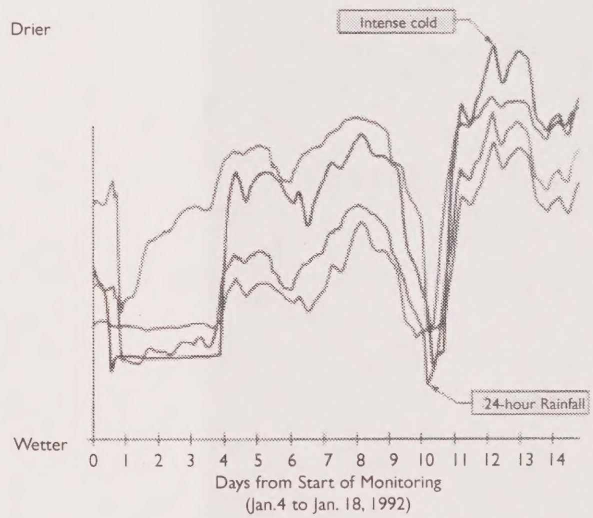
Condensation generally began to form on the back of the brick, on the ties, and on the exterior surface of the sheathing when exterior air temperature fell below 5° C. It began to form on the interior sheathing surface when the exterior temperature was below freezing.

Moisture

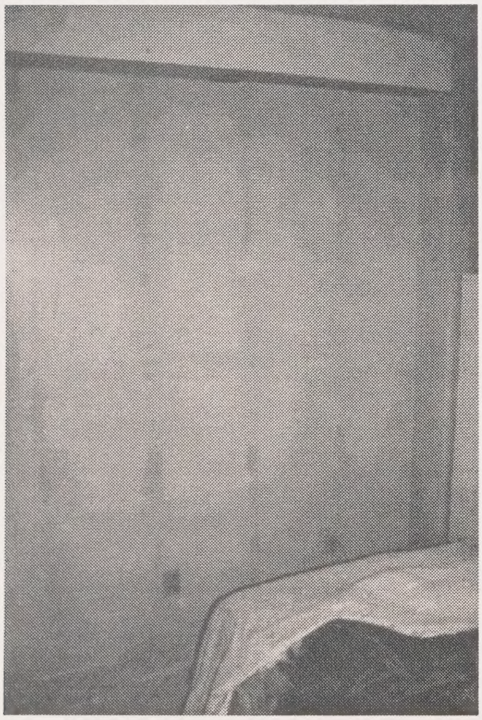
Moisture sensors revealed that in fall, winter, and spring the interior face of the brick was relatively wet, much more so than the exterior. When it rained, the exterior surface rapidly became wet, but dried soon after. Until the vents were added at the top of the cavity, rain penetration performance was satisfactory (after they were added the vents allowed more rain to enter the cavity). Although the wall seemed well constructed and relatively airtight, moisture problems were mainly caused by air leakage. **Figure 6** shows, in relative terms, the amounts of moisture in the brickwork, at inside and exterior faces, for locations near the roof slab, and at the floor level. In order to interpret this graph, remember that when moisture freezes, the sensor reports a false dry condition. This possibility can be judged by reading the exterior temperature, or the sheathing temperature, depending on which surface of the brick is of interest, from **Figure 2**.

Figure 6: Relative wetness of brickwork

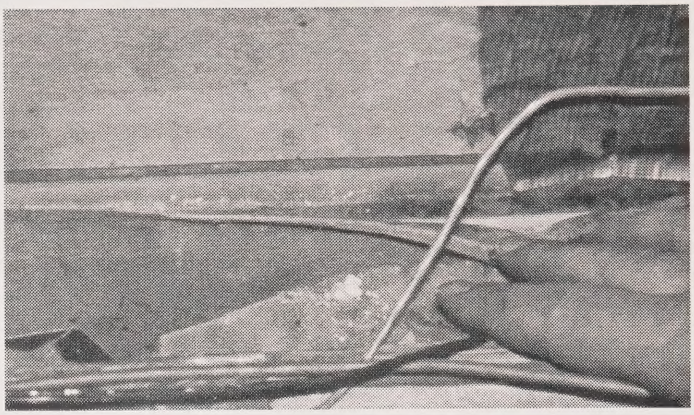
Trace 1: (top at left) brick exterior at floor level
Trace 2: brick interior near roof
Trace 3: brick exterior near roof
Trace 4: (bottom at left) brick interior at floor level



Photograph 4: Dust Staining of Insulation
Evidence of air leakage: dust left behind in the insulation.



Photograph 5: Dust Staining at Stud Locations
Thermal bridging: indoor surfaces at stud locations are colder in winter than the surfaces between studs. More dust is attracted to the cooler surfaces, resulting in the staining seen here.



Photograph 6: Mildew or Mold on Interior Surfaces of Exterior Sheathing
When the wall was opened, this staining was visible on the interior side of the exterior sheathing—here at mid-height, and to a greater extent at the base of the wall.

The cavity did not dry out in cold weather because more moisture condensed from leaking interior air than was removed by evaporation and venting. Throughout the winter season, when freeze-thaw cycling occurred, the back of the brick remained wet. Adding vent holes allowed more moisture to enter the cavity, and did not improve drying. The brick was not uniformly wet—the cavity and the back of the brick dried out only in the summer and were wet for the rest of the year, while the exterior face was drier.

Visual observations

In March of 1994 the wall was opened from the interior for visual inspection of components in the stud space. A small opening was made through the exterior sheathing, to examine the back of the brick. The following observations were made:

- There was no frost or surface moisture on the brick, which appeared fairly dry.
- The building paper and exterior sheathing were very wet and significant amounts of mildew were observed on the interior side of the sheathing, especially at the bottom.
- The insulation in contact with the exterior sheathing was wet.
- Corrosion of the framing was minor. The bottom track showed zinc oxidation (white rust) and signs of periodic wetting. Otherwise, there was rust only on cut edges, screw tips and shavings.

Implications for industry

The key finding of the study is that the test wall did not perform in a satisfactory manner even though it was built in accordance with existing codes, standards, and construction practices. Thermal bridging at the studs and heat lost by air leakage compromised the thermal resistance of the assembly. Accumulations of moisture, mainly due to air leakage, were such that premature deterioration of the brick, ties, and sheathing, if not the framing, is likely. Moisture in the exterior sheathing reached levels that would cause it both to weaken in time and to support mold. Moisture in the brick was not uniformly distributed. At the interior face, during freezing conditions, moisture content was sufficient to eventually cause spalling into the cavity. These findings imply that improved design is required to ensure satisfactory long-term performance of BV/SS wall systems, construction quality notwithstanding. Even with better-than-average workmanship, the following design improvements, relative to the test wall assembly, are recommended:

- Insulation on the exterior, in the cavity, sufficient to keep the gypsum sheathing above the interior air dewpoint temperature (this will also reduce thermal bridging of framing).
- Better airtightness, to reduce latent heat loss and reduce condensation in brickwork.
- A larger minimum cavity depth, to promote drainage and drying.
- Better venting of the cavity (arranged to exclude rain).

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